Macrothink Institute™
Journal of Agricultural Studies
ISSN 2166-0379
2017, Vol. 5, No. 1

Agromorphological Performance and Character Association of Finger Millet under Varying Phosphorus Regimes

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Received: November 22, 2016 Accepted: January 31, 2017 Published: February 24, 2017

doi:10.5296/jas.v5i1.10809 URL: https://doi.org/10.5296/jas.v5i1.10809

Abstract

Finger millet production on more than 30% of world arable land is limited by P availability and more than 70% in the semi-arid and marginalized areas which covers most of the Sub-Saharan Africa. Phosphorus is one of the most important elements significantly affecting plant growth and metabolism. Three finger millet varieties (U-15, P-224 and Ikhulule) were evaluated under four P fertilizer levels (0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5) at the International Crops Research Institute for the Semi-Arid Tropics Station, Alupe and the Kenya Agricultural and Livestock Research Organization Station, Kakamega during the long and short rainy seasons of 2015 with the aim of determining their agromorphological response and trait associations. The on-station experiments were laid out in Randomized Complete Block Design in factorial arrangement with three replications. The statistical analysis of phosphorus levels and variety exhibited significant differences ($P<0.05$) to stand vigor, plant height, leaf blade length, number of leaves and lodging. The results revealed that application of 25 kg ha^{-1} P_2O_5 rate led to the tallest plants (65.0 cm), longest leaf blades (58.0 cm) and highest number of leaves per plant (16) at Alupe site while 37.5 kg ha^{-1} P_2O_5 rate eliciting the tallest plants (58.79 cm), longest leaf blades (51.44 cm) and highest number of leaves per plant (13) at Kakamega site. The highest rate led to the greatest vigor in both sites for both seasons while the control had the poorest vigor. Variety P-224 showed the highest lodging count with 32 out of 246 plants per experimental unit during the rainy season at Kakamega. The unit increase in grain yield was positively and significantly correlated with increased values of the harvest index (r=0.375), number of leaves (r=0.393) and plant height (r=0.431) but negatively and significantly correlated to the 1000-grain mass (r=-0.578) and lodging (r=-0.233). The best phosphorus treatment for most of the parameters was 25 kg ha^{-1} P_2O_5 at Alupe while maximum levels of the study parameters were realized under the 37.5 kg ha^{-1} P_2O_5 rate at Kakamega.

Keywords: Finger millet, arable land, metabolism, agromorphological response

1. Introduction

Finger millet (*Eleusine coracana*) originated and was domesticated in the Eastern African sub-humid uplands (Fetene *et al.*, 2011) making it well suited for Africa's climate. According to FAO (2002), large parts of the Sub-Saharan Africa are semi-arid, with erratic rainfall and nutrient poor soils. Today finger millet is an important crop grown in low input farming systems by resource poor farmers in Eastern Africa and plays a critical role in agriculture and food security of poor farmers that inhabit arid, infertile, and marginal lands. At the same time finger millet grains can be stored for over 10 years without significant deterioration (FAO, 2015). Finger millet being drought tolerant have a strong adaptive advantage and lower risk of failure than other cereals in such environments. It has therefore been noted as staple food grains in many semi-arid and tropic areas of the world, particularly in Sub-Saharan Africa because of their good adaptation to hard environments and their good yield of production (Dicko *et al.*, 2005). In another report by Taylor *et al.* (2006) expanded on Dicko's findings by describing finger millet as generally the most drought-tolerant cereal grain crops that require little input during growth and with increasing world populations and decreasing water supplies, it represents an important crop for future human.

The tropics are characterized by unpredictable weather, limited and erratic rainfall and nutrient-poor soils and suffered from a host of agricultural constraints (Maqbool *et al.,* 2001; Sharma and Ortiz, 2000). Pursuing this further, Sharme *et al.* (2002) highlighted that there is an urgent need to focus on improving crops relevant to the smallholder farmers and poor consumers in the developing countries of the semi-arid tropics and the world at large. This can be through the development of crops that are adaptable to these environments. This can be achieved through increasing production and productivity of these crops. These conclusions concur with those by Taylor *et al.* (2006) that finger millet has the potential to improve household food security in semi-arid regions because of their adaptability to such environments. Despite this, research on these crops has been lagging behind in Africa because they suffer an image problem and there often tends to be a preference for maize as the premier crop.

Finger millet has faced declining use in the world, over the last 50 years due to changing farming systems and low productivity (FAO, 2015). Also data in calorie consumption trends in Kenya indicates millet has lost share among the cereals. Its share has fallen from 6% in 1961 to about 1% in 2011. In 2011 millet production in Kenya was about 73,000 MT. Output has been erratic showing significant variation over the years, indeed yields have remained largely stagnant at about 660 Kg ha^{-1} (FTF, 2011). In western Kenya, yields compare poorly to those recorded in India where yields of between 5000-6000 kg ha^{-1} have been achieved, though these are under irrigated conditions (NRC, 1996). This is a crop that has also been neglected in terms of research and development and even among the neglected African crops millet is still a marginalized crop. One of the major constraint that has hampered production and utilization of the crop include poor soil fertility especially phosphorus. The neglect of the crop has seen it being pushed to more marginal areas with poorer soils and more drought-prone areas Salasya *et al.* (2009). Findings by Tefera *et al.* (2012) reported that in the key millet growing areas only 7.5% had used fertilizer on finger millet in the last two years; similarly the use of organic manure was low at only 5.3% and finger millet farmers are essentially "mining" the soil. Mitigation of this challenge has the potential to increase productivity, food and nutritional security among malnourished poor communities, and ultimately alleviate poverty through marketing of millet. Therefore, the current study was conducted to evaluate the response of finger millet growth and development to applied phosphorus and how the agromorphological traits impact on the eventual grain yield.

2. Materials and Methods

2.1 Site Description

The two on-station experiments were conducted in the crops research stations located in Kakamega and Busia Counties. The Kenya Agricultural and Livestock Research Organization

(KALRO) Station, Kakamega lies within Longitude 4°45’0” E and Latitude 0°16’60” N with an elevation of 1523 metres above sea level. The soils were predominantly sandy loam with 53.55% sand, 32.18% silt and 14.27% clay. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Station, Alupe lies within latitude 0°30” N and Longitude 34°07’50” E with an elevation of 1157 metres above sea level. The soils were sandy loam with 47.57% sand, 35.76% silt and 16.67 % clay. The two sites have two crop growing seasons in a calendar year, the long rainy season (between March and August) and the short rainy season (between September and December). The experiment was carried out in the two seasons of 2015.

2.2 Experimental design and treatments

The experiments were laid out in a randomized complete block design (RCBD) fitted in a factorial arrangement with four levels of phosphate fertilizer supplied as Triple Superphosphate (TSP) as follows: 0, 12.5, 25 and 37.5 kg ha^{-1} P_2O_5 where 0 kg ha^{-1} P_2O_5 was the control and three finger millet varieties: U-15, P-224 and Ikhulule, where Ikhulule was the local check and the treatments were replicated three times. Each experimental plot measured 4 by 2 metres and a 2 m pathway was maintained within each plot. Phosphate fertilizer was wholly applied at planting along the furrows and mixed with the soil to avoid direct contact with seeds when drilled.

2.3 Cultural Operations and Data Collection

Analysis of composite surface soil samples collected from the experimental fields indicated that the soils were moderately acidic (pH in 1:2.5 soil: water ratio of 5.45 in Alupe and 5.60 in Kakamega). The top soils were moderately low in Total N (0.12% in Alupe and 0.18% in Kakamega), high in organic carbon (2.26% in Alupe and 3.40% in Kakamega), low in Olsen extractable P (6 ppm in Alupe and 5 ppm in Kakamega), and moderate in available K contents (0.30% in Alupe and 0.75% in Kakamega). Land preparation was done prior to the onset of rains during both seasons. Planting was done by hand drilling seeds obtained from ICRISAT in rows spaced 40 centimetres between rows and later thinned after four weeks between plants to an intra-row spacing of 10 centimetres to a plant stand of 246 per plot. All other agronomic operations were done as recommended for the crop. The crop was visually observed at 3 weeks after emergence on its vigor and scored on a scale of 1-5; where 1 was for the most vigorous, 2 for vigorous, 3 for intermediate, 4 for poor and 5 for very poor. The plant height was measured using a standard ruler from the stem base to the top node where the leaves segregate on 5 tagged plants and the average recorded in every plot from two weeks after emergence until dough stage at a 4-week interval. The leaf blade length of 5 tagged plants in each plot was measured from the ligule to tip on the 4th leaf from the top (flag leaf) at 4 weeks after emergence and at dough stage. The number of leaves on main tiller of the 5 tagged plants in each plot was counted and the average number recorded after 4 weeks after emergence and at dough stage. The number of lodged plants were counted in the middle rows from every plot. One thousand grains for each experimental unit were counted using an Elmo-C1 STE-10A model seed counter then weighed using a digital Avery (Tronix-model) scale and recorded. The grain yield from the net plot (3 m^2) of every experimental unit was weighed on an Avery scale (Tronix-model) and recorded at 13.5% moisture content. The data was collected as described by the International Board for Plant Genetic Resources (1985) for finger millet descriptors.

2.4 Statistical Analysis

Analysis of variance (ANOVA) was performed on the cleaned data using GenStat statistical software Version 15.1 to test treatment effects at 5% level of significance. The means were separated using Fischer's Protected LSD test where significant differences between treatments were observed. Spearman's rank correlation analysis was conducted to estimate the relationship between the phenotypic variables.

3. Results and Discussions

3.1 Stand Vigor

Significant differences ($P<0.05$) were observed in Kakamega and Alupe for both seasons on the stand vigor due to application of phosphorus (Table 1). The greatest vigor was observed in the highest rate of 37.5 kg ha^{-1} P_2O_5 at both sites while the lowest vigor was exhibited in the control plots.

Table 1. The stand vigor of finger millet as influenced by phosphate rates and variety in Kakamega and Alupe, Kenya for the short and long rainy seasons of 2015

	Kakamega		**Alupe**	
Phosphate Rates	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**
Control	2.78a	3.44a	3.33a	3.44a
12.5	2.44b	2.55b	2.22b	2.67b
25	2.44b	2.11b	1.89b	2.56b
37.5	1.67c	2.89b	1.89b	2.11b
Variety				
U-15	2.75b	2.75c	2.08a	3.00a
P-224	3.33ab	3.75a	2.58a	3.17a
Ikhulule	3.92a	3.25b	2.33a	2.67a

Values followed by different letters within the column are significantly different

However, the P applied treatments did not differ significantly except at Kakamega during the short rainy season where the 37.5 kg ha^{-1} P_2O_5 was significantly the highest. Significant varietal differences were observed only at Kakamega site where variety U-15 showed the highest vigor for both seasons while variety P-224 had the lowest. Deficiency of P has been found to be one of the most important restrictive factor in plant growth and promotes root development that enhanced uptake of other essential elements (Alinajati and Mirshekari, 2011) and therefore the increased vigor in Kakamega and Alupe was due to optimal availability of phosphorus. This findings are in tandem with those by Sharma (2002) who reported that one of the advantages of feeding the plants with phosphorus is to create deeper and more abundant roots that enhances establishment of crops

3.2 Plant Height

The application of phosphorus significantly and positively influenced the crops height in both sites for both seasons. At Kakamega, the growth of finger millet was linear with increase in application rates of phosphorus from week 2 after emergence to dough stage. In Alupe, the crops had the longest stature at the 25 kg ha^{-1} P_2O_5 treatment at 8 and 12 weeks after emergence while during the earlier weeks, a direct proportional effect on the plant height was observed with increasing rates to the highest rate which was also observed at Kakamega site throughout the sampling periods (Figure 1). At both sites and seasons, the control plots had the shortest statured plants. The varieties showed significant differences ($P<0.05$) on the plant height especially after 8 weeks from emergence where the local variety, Ikhulule was the tallest (62.0 cm) in Kakamega and variety P-224 (86.0 cm) at Alupe while minimal differences were observed between the varieties in early vegetative stages.

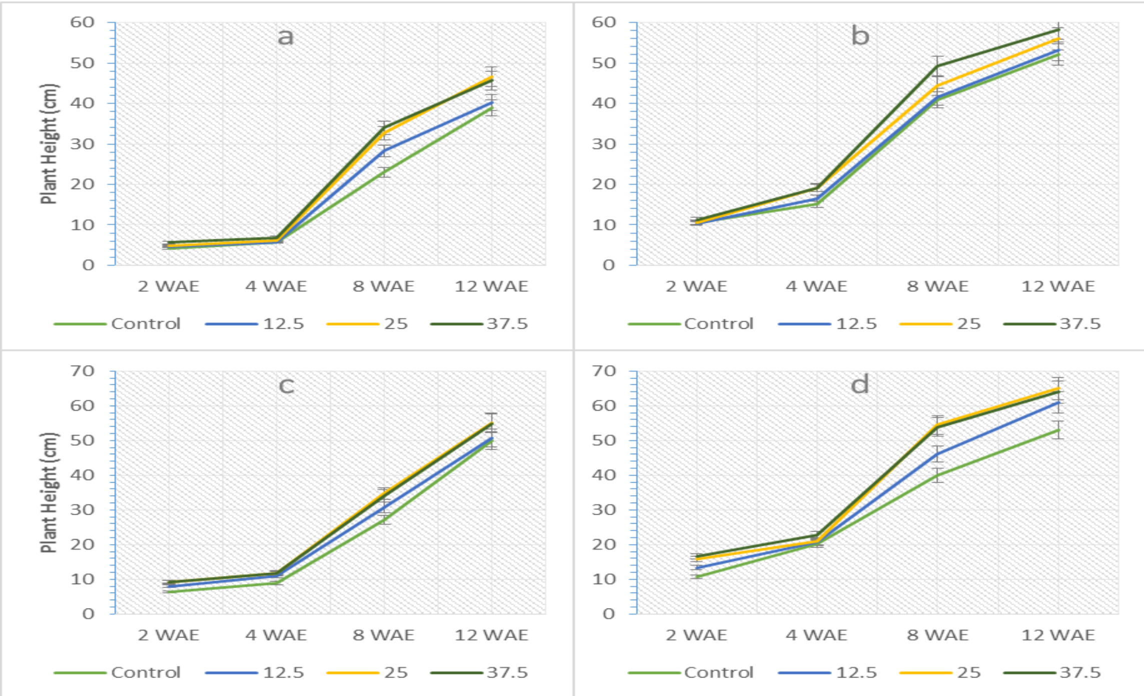

Figure 1. The effect of phosphate rates on the height of finger millet during the short (a) and long (b) rainy seasons at Kakamega, and during the short (c) and long rainy seasons at Alupe in Kenya, 2015

The importance of P application was realized on the increase in the height in the P applied treatments over the control which could be due to the increase in the nutrient uptake efficiency of the different crop varieties that likely contributed to increased plant height. The significant increase in plant height might also be because phosphorus improved the root development which had a great effect on the plant height, probably due to advanced root system that increased nutrient absorption (Hussain *et al.,* 2006). These findings are in conformity with those by other scientists (Okalebo *et al.*, 1990; Sahoo and Panda, 2001) who found significant increase in height of maize with P application over that of the control. In another study similar results were reported where application of phosphorus fertilizer increased plant height gradually in two sorghum cultivars (Khalid and Muhammad, 2003).

3.3 Leaf Blade Length

The leaf blade had significant differences (P<0.05) at Kakamega and Alupe due to phosphate fertilizer application at 4 weeks after emergence and at dough stage. Plots without P exhibited the lowest blade length at both stages (Table 2). At Alupe, the highest blade length was realized at 25 kg ha^{-1} P_2O_5 a further increase phosphorus led to a decrease while at Kakamega, phosphorus supply at the highest rate still showed a linear elongation of the leaf blades in both seasons for both sampling stages. There were no significant differences between the varieties on the leaf blade length.

Table 2. The leaf blade length of finger millet as influenced by phosphate rates and variety in Kakamega and Alupe, Kenya during the short and long rainy season, 2015

	4 WAE				Dough Stage			
	Kakamega		Alupe		Kakamega		Alupe	
Phosphate Rates	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**
Control	12.69b	11.27ab	36.79c	14.6b	38.82b	46.33b	53.76a	52.7a
12.5	14.49b	10.53b	39.81b	19.5a	42.11a	48.78ab	54.31a	55.3ab
25	14.33b	11.16ab	44.64a	23.2a	42.69a	49.21a	54.13a	58b
37.5	18.04a	11.73a	42.09a	22.5a	43.8a	51.44a	53.29a	57.6b
P-Value	***<.001***	***0.049***	***<.001***	***<.001***	***0.012***	***0.025***	***0.971***	***<.001***
Variety								
U-15	13.37b	11.12a	40.77a	20.6a	40.9a	48.47a	54.23a	55.2a
P-224	15.47a	11.23a	41.19a	20.2a	42.63a	48.84a	55.1a	56.8a
Ikhulule	15.83a	11.17a	40.53a	19.1a	42.03a	49.51a	52.29a	55.8a
P-Value	***0.004***	***0.957***	***0.89***	***0.399***	***0.611***	***0.728***	***0.363***	***0.276***

Values followed by different letters within the column are significantly different

Similar findings on the increase of leaf blade length were reported that P fertilizer increased the leaf length of pearl millet (Payne *et al.*, 1991). It has also been found that when the hydraulic conductivity reduces in the root and decrease in stomatal conductance of the leaf, they cause severe reduction of leaf expansion under P-deficiency (Clarkson *et al.*, 2000). The leaf blade length elongation was lowest in the controls in all the sites. This was due to the reduced supply of P compared to the other treatments leading to low energy support in the plant. This result is supported by Plenet *et al.* (2000), who found that low biomass accumulation is mainly due to the effect of P deficiency on leaf growth.

3.4 Number of Leaves

Positive responses were observed in the number of leaves per plant due to application of phosphorus at Kakamega and Alupe at 4 weeks after emergence and at dough stage in both seasons as shown on Table 3. Increasing P rates increased the number of leaves up to 25 kg ha^{-1} P_2O_5 and thereafter decreased in Alupe but otherwise in Kakamega where the number of

Journal of Agricultural Studies
ISSN 2166-0379
2017, Vol. 5, No. 1

leaves per plant continued to increase until the highest rate. The varieties differed significantly where P-224 and Ikhulule showed the highest leaf number per plant in both sites (Table 3).

Table 3. The influence of phosphate rates and variety on the number of leaves per plant in Kakamega and Alupe, Kenya during the long and short rainy seasons, 2015

	4 WAE				**Dough Stage**			
	Kakamega		**Alupe**		**Kakamega**		**Alupe**	
Phosphate Rates	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**
Control	5.00c	6.02a	10.78b	6.60b	11.53a	12.52b	16.22a	14.00b
12.5	6.00b	6.09a	11.67a	7.50a	11.38a	12.43b	16.11a	15.00ab
25	6.00b	6.16a	11.89a	7.90a	11.64a	13.67a	15.89a	16.00a
37.5	7.00a	6.07a	11.78a	7.60a	11.98a	13.37a	15.78a	16.00a
P-Value	***0.022***	***0.687***	***0.037***	***0.004***	***0.482***	***0.049***	***0.91***	***0.005***
Variety								
U-15	5.90a	6.17a	11.5ab	7.20a	11.15b	12.58a	14.58b	15.00b
P-224	6.07a	6.07a	12.08a	7.50a	11.77a	13.24a	16.75a	15.00b
Ikhulule	6.25a	6.12a	11.00b	7.40a	11.98a	13.17a	16.67a	16.00a
P-Value	***0.184***	***0.499***	***0.034***	***0.563***	***0.047***	***0.271***	***0.002***	***0.021***

Values followed by different letters within the column are significantly different

The increment in the number of leaves was probably due to the importance of phosphorus in cell division activity, leading to an increase in leaf number where optimal P was applied. This conforms to another finding by Tesfaye *et al.* (2007) who studied P stress in legumes. In another report, it was found that the decrease in leaf number and size is one of the earliest and most reliable responses of plants to P-deficiency (Lynch *et al.*, 1991). This is so because leaf expansion occurs due to the multiplication of cells and elongation of the newly formed cells where P plays a crucial role in supplying the energy as well as enhancing the turgor pressure which is important in the cycle (Hsiao, 1973; Munns *et al.*, 2000).

3.5 Lodging

Significant influence of phosphate fertilizer application was only observed during the long rainy season at Kakamega while no significant differences between phosphate treatments were revealed in the short rainy season and for both seasons at Alupe. However, varietal differences were observed on the lodging count in both sites where at Kakamega, variety P-224 had the highest lodging count while the local variety, Ikhulule had the highest lodging count at Alupe.

Table 4. The lodging count per plot of finger millet as influenced by phosphate rates and variety in Kakamega and Alupe during the short and long rainy seasons, 2015

	Kakamega		**Alupe**	
Phosphate Rates	**Short Rain**	**Long Rain**	**Short Rain**	**Long Rain**
Control	5.22a	9.04b	23.5a	22.8a
12.5	3.81a	15.03ab	18.3a	27.1a
25	5.78a	16.07a	19.2a	29.6a
37.5	4.31a	16.69a	20.3a	29.1a
P-Value	***0.402***	***0.041***	***0.438***	***0.477***
Variety				
U-15	2.94c	6.55b	18a	16.8b
P-224	6.41a	31.97a	20.2a	22.8b
Ikhulule	4.98b	4.1b	22.8a	41.9a
P-Value	***0.013***	***<.001***	***0.271***	***<.001***

Values followed by different letters within the column are significantly different

This findings on lodging agree with the report that under optimal fertilizer application and an expected optimum fertilizer application, high incidences of lodging occurs (Oduori, 2005). Plant height is known to be positively correlated to lodging which makes the plant vulnerable to strong winds and rainfall as well as supporting its own weight and that is why the lowest lodging was recorded on the shorter variety, U-15. This agrees with Mohr *et al.* (2007) who found that higher lodging scores under fertilized conditions which were likely due to taller and/or denser plant stands and heavier panicle densities in oats.

3.6 Character Associations

The grain yield was positively and significantly correlated (P<.001) to the harvest index (r=0.375), leaf number (r=0.393), plant height (r=0.431) and the seedling vigor (0.301) as shown on Table 5. Negative and significant correlations (P<.001) were observed between the grain yield and 1000-grain mass (r=-0.578), and the grain yield and the lodging count (r=-0.233). The leaf blade length was positively and significantly correlated with the number of leaves as well as the plant height and the lodging count as shown on Table 5.

Phosphorus is an important component in many physiological activities that occur within developing and maturing plants where it is involved in various enzymatic reactions in the crop. Phosphorus is a constituent element of nucleoproteins essential for cell division and cell reproduction processes (Brady and Weil, 2002). Phosphorus is also essential in the reactions of carbohydrate synthesis and degradation as a chemical component. Therefore, by supplying phosphorus at optimal levels to crops enhances growth which can be a prerequisite for better yields. Phosphate fertilizer increased the leaf blade length which showed direct positive correlation with the grain yield. Similar findings have been reported Chaudhry *et al.* (2003) in pearl millet where longer leaves had direct positive influence on the grain yield. This is due to the high capacity to intercept light and thereby increasing the photosynthetic rate. Similar correlations were also found by Dewey and Lu (1959) in crested wheat. The number of leaves showed a positive correlation with the grain yield which indicates the importance of higher leaf number in increasing the nutrients sink source of finger millet. Increase in the sink size of crops elevates plants metabolism that leads to greater yielding. This is in tandem with an earlier report by Subedi and Budhathoki (1996). The correlation between the grain yield and the 1000-seed mass was found to be significant and negative due to the plants mechanism to use more photo-assimilates at the expense of grain filling leading to low grain weights, hence significantly reducing the total grain yield of finger millet. This was also confirmed by Yan and Wallace (1995). Taller plants tended to lodge more than shorter ones and lose their yield thus the negative correlation between grain yield and lodging count and a positive correlation between plant height and lodging count. Lodging has been considered as a major yield limiting factor in finger millet production where it has a potential to slow harvest, and to reduce yield and quality (Oduori, 2005).

Table 5. Spearman's rank correlation coefficients between eight (8) finger millet quantitative traits for combined environments (Kakamega and Alupe) and seasons (Long and Short) of 2015 in Kenya

1	1	2	3	4	5	6	7	8
2	-0.578***	-						
3	-0.461	0.375***	-					
4	0.162	0.393***	-0.255	-				
5	-0.208	0.018	0.073	0.676**	-			
6	-0.119	-0.233**	0.213	0.485	0.529**	-		
7	-0.687	0.431***	0.433	0.250	0.594**	0.403**	-	
8	-0.313	0.301**	0.326	-0.053	0.066	0.228	0.312	-

*1=1000-Grain mass, 2=Grain yield, 3=Harvest Index, 4=Leaf Number, 5=Leaf blade length, 6=Lodging Count, 7=Plant height, 8=Stand vigor, ***=Highly significant, **=Significant*

4. Conclusion

Application of phosphorus had positive effect on seedling vigor, number of leaves, plant height, and leaf blade length of finger millet. All these traits were found to have positive influence on the eventual grain yield and therefore application of P is a precursor for higher yields. Results from this study therefore suggest that the low rates of applied phosphorus might correct the P deficiency experienced in finger millet production.

Acknowledgement

Authors would like to thank all the staff of ICRISAT-Nairobi and KALRO-Kakamega especially Dr. Chrispus Oduori, Dr. Rachel Opole, Mr. Daniel Ajaku Otwani, Mr. Aggrey Omutsani and Mr. Edwin Machinji for their full support in this project.

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